APPENDIX IV

Simplified Procedures for Preliminary Determination of Embankment Slopes

1. General. Two methods for determining approximate embankment slopes using design charts are presented in this appendix. The methods are useful for determining approximate embankment slopes prior to more detailed analyses by the methods outlined in Appendixes VI, VII, and VIII. The first method is applicable to homogeneous clay embankments and foundations overlying a rigid boundary and assumes that failure occurs along a circular arc as shown in plate IV-1. The second method is applicable to homogeneous cohesionless embankments on shallow clay foundations overlying a rigid boundary and assumes that failure occurs along plane surfaces in the foundation and in the embankment as shown in plate IV-6. These methods of analyses are applicable for cases involving no seepage. Due to the differences in the basic assumptions of the two methods presented, comparisons of factors of safety should be made with caution. Other charts such as those prepared by Janbu[12] or Scott[13] may also be used; they yield more conservative results because they apply to slopes having horizontal or wide crests.

2. Homogeneous Embankment and Foundation Overlying a Rigid Boundary.

a. The design charts are developed for the general case of a homogeneous embankment and foundation overlying a rigid boundary as shown in plate IV-1. The embankment slopes are assumed to be symmetrical, and the crown width is equal to one-eighth the embankment height. In plates IV-2 through IV-5, the stability factor $N_s = \frac{\gamma H}{c_D}$ is presented for ratios of thickness of foundation layer D to embankment height H between 0 and 1. Embankment slopes are limited in these plates to those between 1 vertical on 2 horizontal and 1 vertical on 4 horizontal. The stability factor is related to shear strength of the soil by values of developed angles of internal friction ϕ_D for the embankment and foundation between 0 and 25 deg, with no restrictions as to developed values of cohesion. The critical arc originates on the slope opposite that under investigation and emerges at or beyond the toe of the embankment, depending on the relative thickness of the impervious embankment and foundation layer. (The method given in this section is not suitable for cohesionless embankments on clay foundations.) The following example illustrates the use of the charts.

Example: A homogeneous earth embankment, 120 ft high, is to be constructed on a clay foundation, 40 ft thick, underlain by bedrock. The unit weight of the foundation and the unit weight estimated for the compacted embankment are 110 lb per cu ft. Results of Q tests indicate that a design shear strength of $c = 950$ lb per sq ft, $\tan \phi = 0.165$ may be used for the foundation and embankment. What slope having a factor of safety of 1.3 should be used as a basis for a detailed analysis of the end-of-construction condition? The values to be used in the appropriate design charts are as follows.

$$\frac{D}{H} = \frac{40}{120} = 0.33$$

$$c_D = \frac{950}{1.3} = 731 \text{ lb per sq ft}$$

$$\tan \phi_D = \frac{0.165}{1.3} = 0.127 \quad \text{and}$$

$$\phi_D = 7.2 \text{ deg}$$

$$\text{Stability factor } N_s = \frac{\gamma H}{c_D} = \frac{110 \times 120}{731} = 18$$

From plate IV-4, the stability chart for $D/H = 0.25$, the slope corresponding to a stability factor of 18 and a $\tan \phi_D$ of 0.127 is approximately 1 on 3.30; from plate IV-3, the stability chart for $D/H = 0.50$, the slope is found to be 1 on 3.55. By interpolation, an embankment slope of 1 on 3.38 is indicated for $D/H = 0.33$. Thus, an embankment slope of 1 on 3.5 may be chosen for more detailed analysis.

b. The design charts are limited to cases where the embankment and foundation soils have similar unit weights and shear strengths. Otherwise, weighted averages are required and a trial failure arc must be selected. Such a refinement is not considered justified since the effort involved can be more appropriately used in detailed stability analyses.

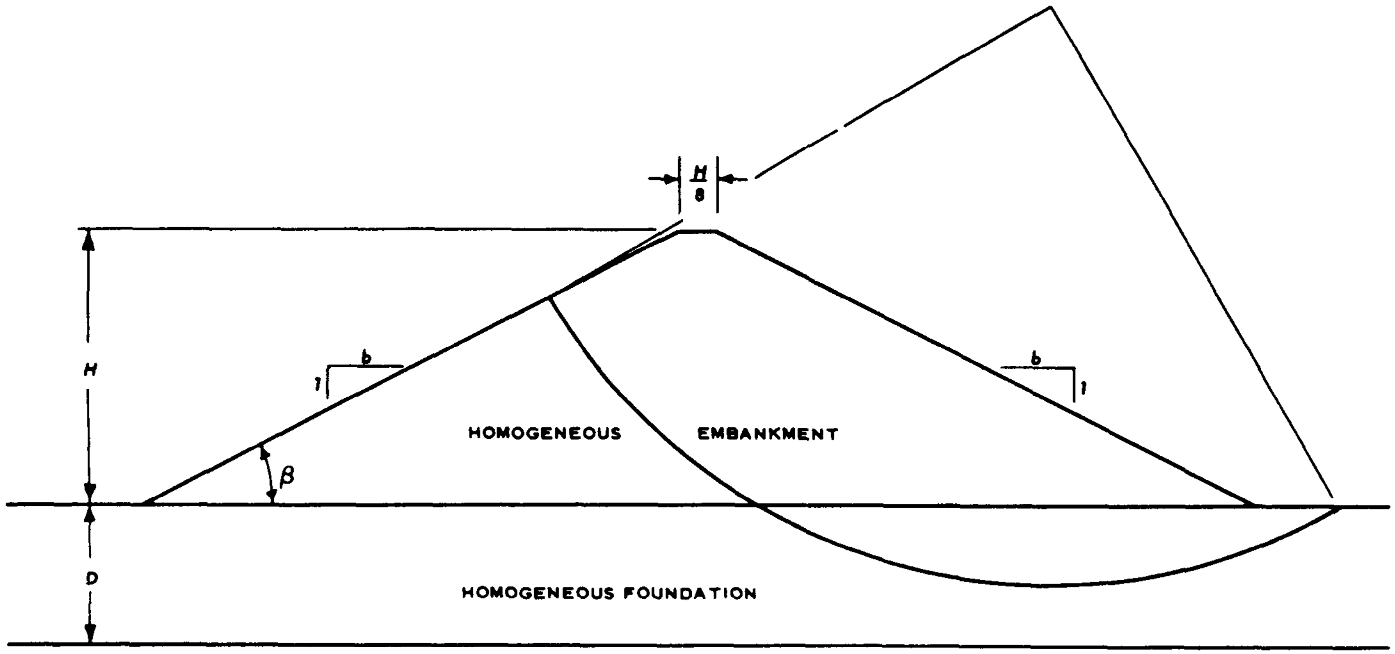
3. Embankment on Shallow Clay Foundations Overlying a Rigid Boundary. The outer slopes of a symmetrical embankment of cohesionless material resting on a shallow clay foundation overlying a rigid boundary, as shown in plate IV-6, can be approximated from figure 1 in plate IV-7. This chart utilizes an active earth pressure coefficient K_A corresponding to the ratio of the horizontal to vertical earth pressures at the center of the dam. Figure 2 in plate IV-7 gives values of K_A for a horizontal ground surface and for negative slopes (i.e. reverse slope on opposite side of embankment). A design slope can be estimated by determining a value of K_A from figure 2 of plate IV-7 for an assumed embankment slope and substituting this trial value of K_A in figure 1 to obtain a value of the stability number $N_K = \frac{b\,c_D}{\gamma H}$ and a corresponding slope. This slope can then be used to determine a second trial value of K_A from figure 2, if necessary, and a revised stability number and slope from figure 1. A few trials are adequate, as the value of K_A changes slowly for small changes in slope angles and the stability number is relatively insensitive to small changes in K_A. The stability chart in figure 1 of plate IV-7 assumes that the thickness of plastic foundation soil is small. The shear strength of the foundation soil corresponds to the Q shear strength and is expressed in terms of an equivalent cohesion c. The shear resistance along the failure plane in the embankment is taken into account by the earth pressure coefficient. The following example illustrates the use of the chart.

Example: A homogeneous embankment, 100 ft high, having a shear strength corresponding to an angle of internal friction of 28 deg and a unit weight of 120 lb per cu ft is to be constructed on a layer of clay, 10 ft thick, having a shear strength of 1200 lb per sq ft. What approximate slope should be used in an analysis of the stability of the dam for a factor of safety of 1.3? The developed angle of internal friction ϕ_D of the embankment is 22 deg $\left(\tan \phi_D = \frac{0.532}{1.3} = 0.409\right)$. The developed cohesion c_D of the foundation is $\frac{1200}{1.3} = 923$ lb per sq ft. The ratio of D/H is 0.1. As a first trial, the value of K_A, assuming a slope of 1 on 4-1/2, is 0.40. From figure 1 of plate IV-7 for $D/H = 0.1$ and $K_A = 0.40$, the stability number N_K is 0.300. Solving for b in the equation

$$N_K = \frac{b\,c_D}{\gamma H} \quad \text{or} \quad b = \frac{N_K \gamma H}{c_D}$$

$$b = \frac{0.300 \times 120 \times 100}{923} = 3.9$$

Thus, a slope of 1 on 4 may be selected for detailed analysis; additional trial values of K_A are unnecessary.



H = HEIGHT OF EMBANKMENT

D = DEPTH OF FOUNDATION LAYER

N_s = STABILITY FACTOR = $\gamma H / c_D$

c_D = DEVELOPED COHESION PER UNIT OF AREA

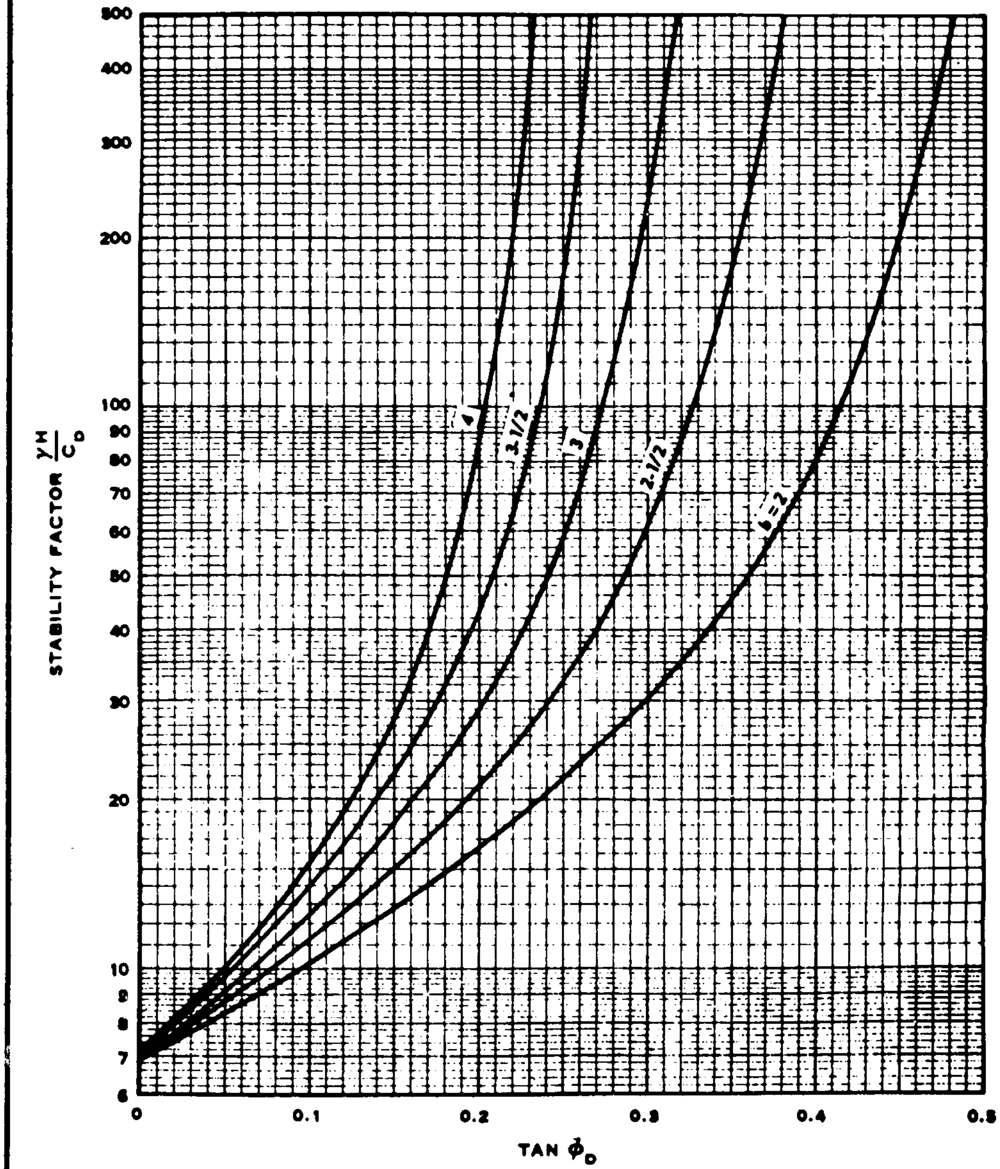
γ = WEIGHT OF EMBANKMENT AND FOUNDATION MATERIAL PER UNIT OF VOLUME

TAN ϕ_D = TANGENT OF DEVELOPED ANGLE OF INTERNAL FRICTION

b = COTANGENT OF SLOPE ANGLE β

CROSS SECTION AND SYMBOLS FOR STABILITY CHARTS

(SEE PLATES IV-2 THROUGH IV-5)

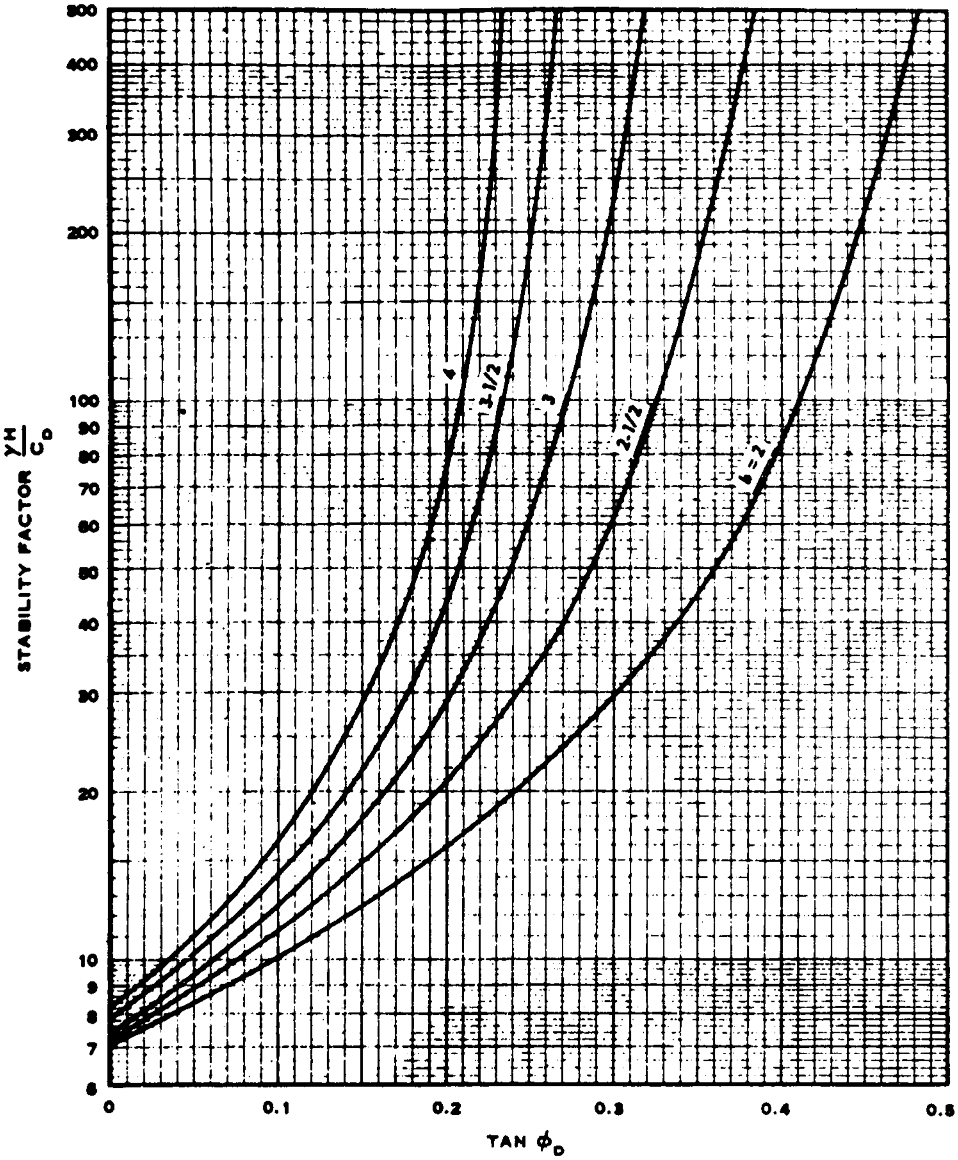


NOTE: SEE PLATE IV-1 FOR DEFINITIONS OF SYMBOLS.

STABILITY CHART FOR HOMOGENEOUS EMBANKMENT AND FOUNDATION.

FOUNDATION DEPTH-EMBANKMENT HEIGHT RATIO, D/H = 1.0

Plate IV-2

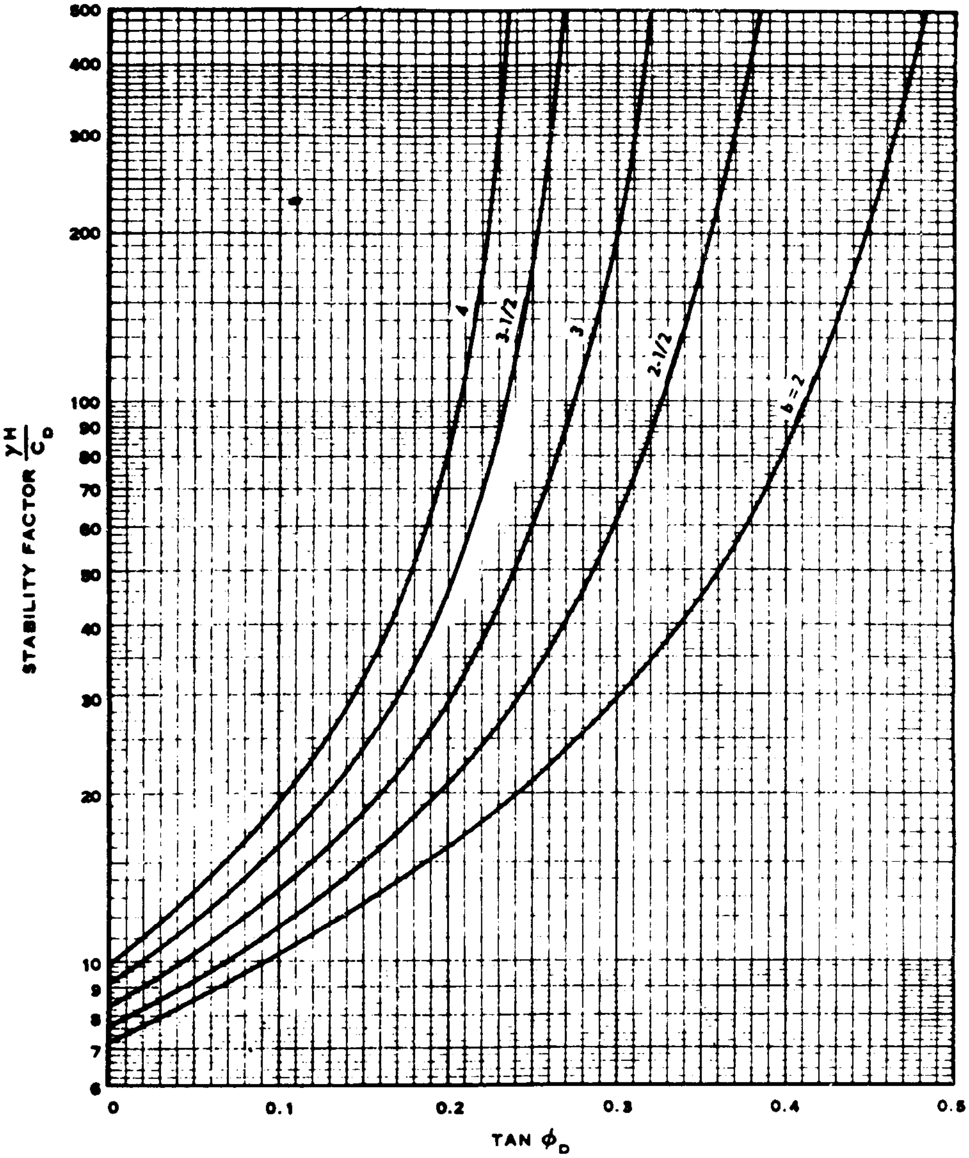


NOTE: SEE PLATE IV-1 FOR DEFINITIONS OF SYMBOLS.

STABILITY CHART FOR HOMOGENEOUS EMBANKMENT AND FOUNDATION

FOUNDATION DEPTH-EMBANKMENT HEIGHT RATIO, D/H = 0.50

Plate IV-3

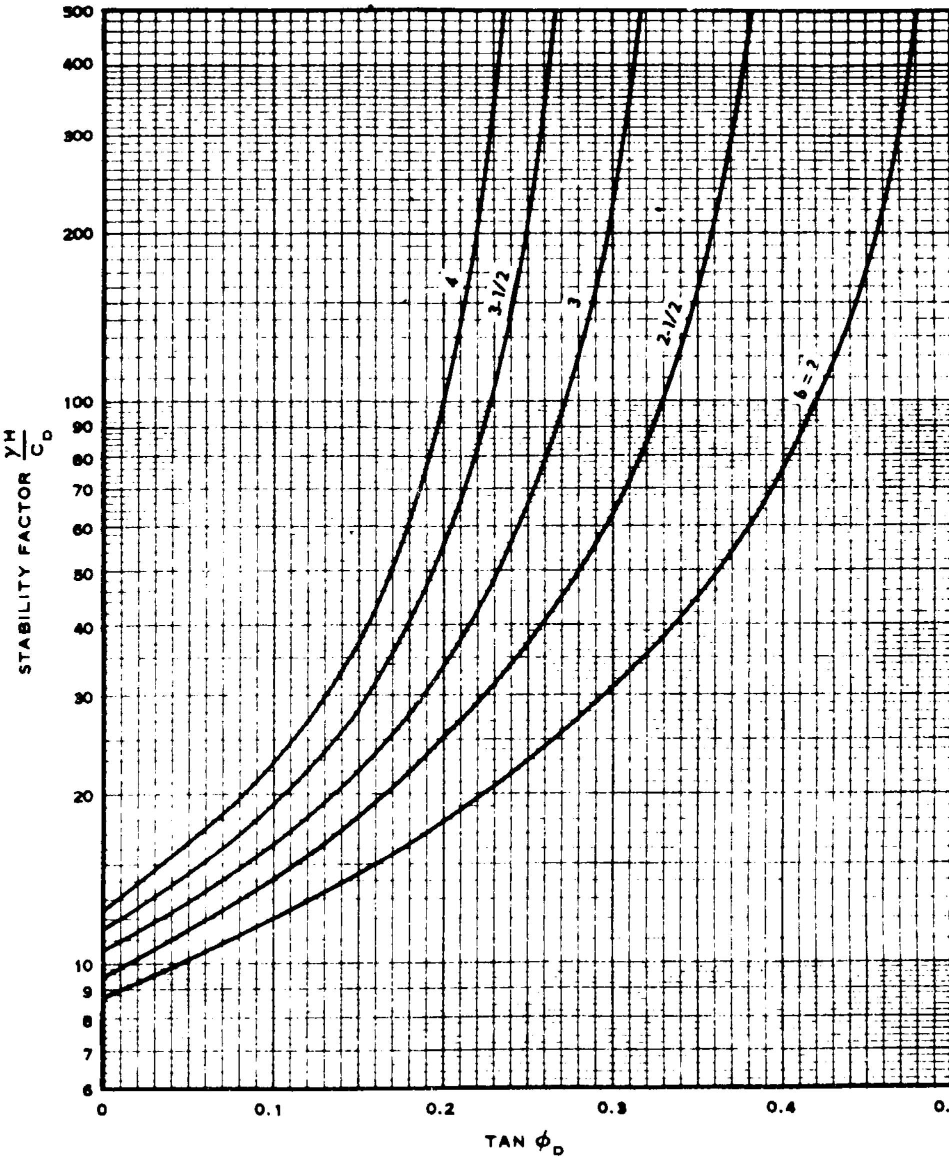


NOTE: SEE PLATE IV-1 FOR DEFINITIONS OF SYMBOLS.

STABILITY CHART FOR HOMOGENEOUS EMBANKMENT AND FOUNDATION

FOUNDATION DEPTH-EMBANKMENT HEIGHT RATIO, D/H = 0.25

Plate IV-4

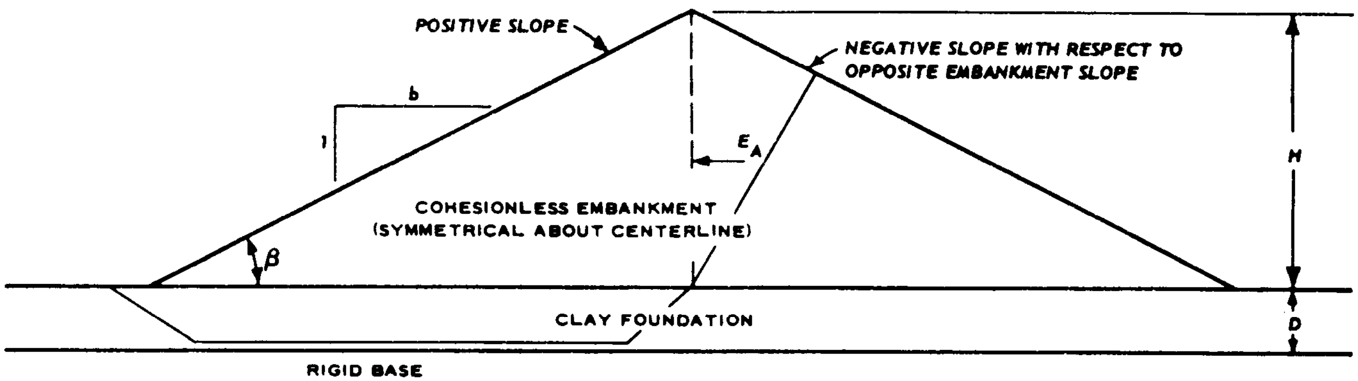


NOTE: SEE PLATE IV-1 FOR DEFINITIONS OF SYMBOLS.

STABILITY CHART FOR HOMOGENEOUS EMBANKMENT AND FOUNDATION

FOUNDATION DEPTH-EMBANKMENT HEIGHT RATIO, D/H = 0

Plate IV-5



H = HEIGHT OF EMBANKMENT
D = THICKNESS OF CLAY FOUNDATION LAYER
K_A = RATIO OF HORIZONTAL TO VERTICAL EARTH PRESSURES, ACTIVE CASE
b = COTANGENT OF SLOPE ANGLE, β
γ = WEIGHT OF EMBANKMENT AND FOUNDATION MATERIAL PER UNIT OF VOLUME
c = COHESION PER UNIT AREA OF FOUNDATION SOIL

CROSS SECTION AND SYMBOLS FOR STABILITY CHART

(SEE PLATE IV-7)

Plate IV-6

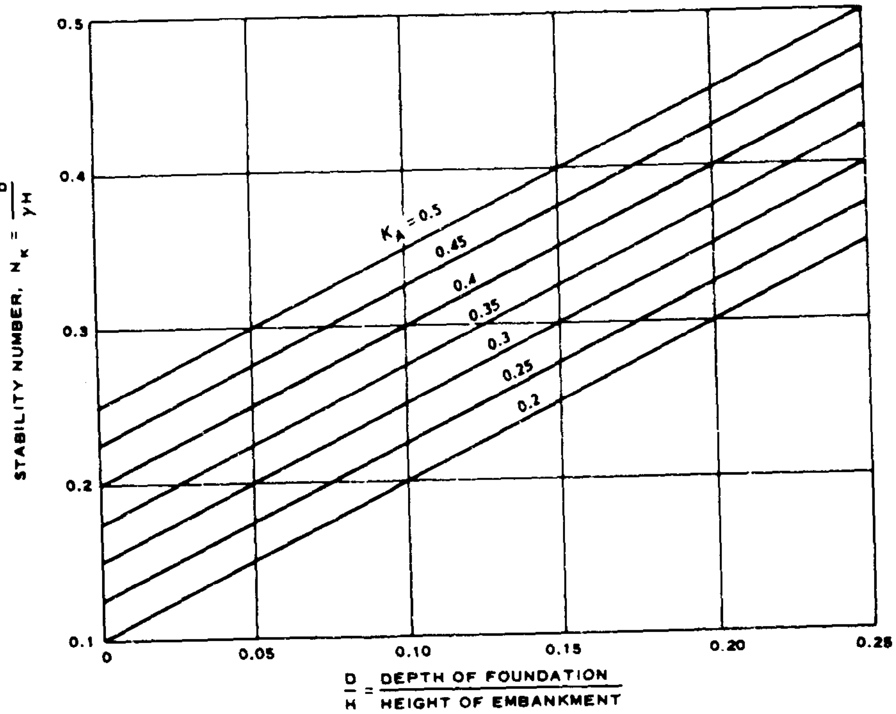


FIGURE 1. N_K VERSUS K_A AND $\frac{D}{H}$

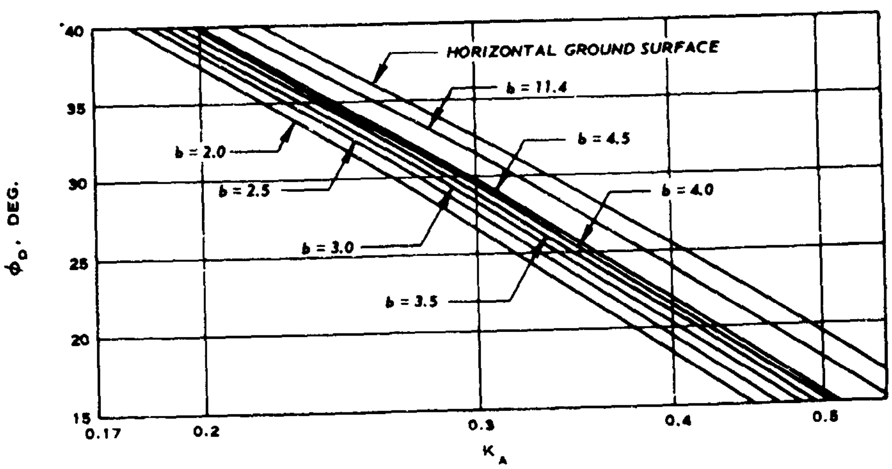


FIGURE 2. ϕ_D VERSUS b AND K_A

STABILITY CHART FOR COHESIONLESS EMBANKMENT ON PLASTIC FOUNDATION

Plate IV-7